ESD-TR-67-121

PERFORMANCE EVALUATION OF TELETYPE ERROR CONTROL EQUIPMENT ON AN ETR CIRCUIT

SEPTEMBER 1967

ESSI

F. N. Nelson, Jr.

Prepared for

DEPUTY FOR SURVEILLANCE AND CONTROL SYSTEMS
AEROSPACE INSTRUMENTATION PROGRAM OFFICE

ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

Project 705B
Prepared by
THE MITRE CORPORATION
Bedford, Massachusetts
Contract AF19(628)-5165

ESD-TR-67-121 MTR-366

PERFORMANCE EVALUATION OF TELETYPE ERROR CONTROL EQUIPMENT ON AN ETR CIRCUIT

SEPTEMBER 1967

F. N. Nelson, Jr.

Prepared for
DEPUTY FOR SURVEILLANCE AND CONTROL SYSTEMS
AEROSPACE INSTRUMENTATION PROGRAM OFFICE
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

Project 705B
Prepared by
THE MITRE CORPORATION
Bedford, Massachusetts
Contract AF19(628)-5165

FOREWORD

This report was prepared by the Range Communications Planning and Technology Subdepartment of The MITRE Corporation, Bedford, Massachusetts, under Contract AF 19(628)-5165. The work was directed by the Development Engineering Division under the Aerospace Instrumentation Program Office, Air Force Electronics Systems Division, Laurence G. Hanscom Field, Bedford, Massachusetts. Captain J. J. Centofanti served as the Air Force Project Monitor for this program, identifiable as ESD (ESSI) Project 5932, Range Digital Data Transmission Improvement.

REVIEW AND APPROVAL

Publication of this technical report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

C. V. Horrigan

f.- OTIS R. HILL, Colonel, USAF
Director of Aerospace Instrumentation
Program Office

ABSTRACT

This report describes a series of teletype transmission tests made over an HF radio link between Mahe Island and Cape Kennedy, Florida. Two methods of error control protection were employed and their relative performances evaluated.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

During the period of 20 September to 29 September 1966, tests were conducted at Cape Kennedy Air Force Station by MITRE personnel to evaluate the operational performance of two teletype circuits used by the SCF (Satellite Control Facility) in Sunnyvale, California for communications with the SCF Indian Ocean Station (IOS). The circuits are routed via landline to Cape Kennedy and thence to the IOS on Mahe in the Seychelles Islands over HF radio paths with a relay at Ascension Island. Previous results obtained during tests conducted in August 1966 on the entire circuit were inconclusive due to operational and equipment problems that were experienced. Both circuits utilize error control techniques to improve the operational performance of the circuit. Since the error control equipment is located at Cape Kennedy Air Force Station to permit closer monitoring of the system operation, the tests described herein were conducted from CKAFS to Mahe on the HF radio portion of the teletype circuits only. This portion of the circuit should reflect the operational performance of the entire circuit if the landline segment is operating properly.

SECTION II

TEST OBJECTIVE

The objective of this test program was to determine the operational performance of the two circuits, with each employing a different error control technique. Idential teletype data was transmitted simultaneously over both circuits, which are multiplexed on a single H.F. radio sideband, to obtain data under the same propagation conditions. At the receiving terminal, a replica of the transmitted data was obtained on teleprinter page copy and the errors identified. Since the two systems required different amounts of time to transmit the same information, the time differential was also noted to provide a basis of comparison other than error rate performance only.

SECTION III

ERROR CONTROL TECHNIQUE DESCRIPTION

W. U. EDAC

Different error control techniques and operational concepts are used on the two teletype circuits. One technique, used on circuit 8001, is an ARQ (automatic retransmission request) system called EDAC (Error Detection and Correction) that was developed by Western Union. In this system, four start-stop teletype characters (20 information bearing bauds - neglecting the start and stop bauds) are encoded within a 30 bit block. Five of the ten remaining bits are used for error detection purposes at the receive terminal and the remainder are used for synchronization and ARQ signaling. This technique requires a full duplex teletype circuit, since, if an error is detected at the receive terminal, a signal must be sent to the transmit terminal directing a repeat of the erroneous block. This condition (continuous requests for retransmission) will prevail until the block is received correctly or until the error detecting code is defeated and the faulty block is erroneously processed as being correct -- resulting in a data output error. Because of retransmission delays inherent in the ARQ technique, this system will not satisfy those operational requirements which involve either real time data communications and/or online security equipment.

CODEX TD-12

The second error control technique is a forward error correction (FEC) system. The equipment developed by Codex Corporation is designated the TD-12 Telegraphy Error Corrector and was operated on circuit 8003. The system concept of this technique is considerably different from that of the EDAC system since this system attempts to correct the data errors that occur during transmission as the data is received. (No provision is made for retransmission.) The code employed is a half-rate (a parity bit for each information bit), convolutional code capable of detecting and correcting random errors (up to 2 errors within a twelve bit block). Burst error protection is provided by interleaving 22 bits between each information bit and its associated parity bit which reduces the impact of error clusters and facilitates correction. The TD-12 equipment can accept synchronous serial data or start-stop (asynchronous) teletype data; therefore, unlike the EDAC equipment, the TD-12 will operate with online security equipment and also has the capability of real time data transfer except for the fixed 22 bit interleaver delay at the decoding terminal.

SECTION IV

TEST PROCEDURE

Initially, it was planned that punched paper teletype tapes would be sent simultaneously via both error control systems from CKAFS to the IOS. At IOS, the received data was to be perforated on paper tape and looped back to the Cape. However, due to a lack of perforating equipment at the IOS and because of operational problems at the Cape, this procedure was abandoned and one-way testing was conducted on both teletype circuits with CKAFS serving as the receiving terminal.

At Cape Kennedy, the received data was demodulated and the digital data applied to the error control equipment for decoding purposes. Printed page copy was then obtained from the output teletype characters of the EDAC and TD-12 equipments. Due to the delay required by the ARQ system for retransmission to correct the errors, a stop watch was used to measure the elapsed time differential required to transmit the same information with each system. In addition, a best case estimate of an unprotected channel error rate was derived from the delays experienced by the ARQ system.

SECTION V

EQUIPMENT CONFIGURATION

Fig. 1 shows a block diagram of the equipment configuration used in the two test circuits between IOS and CKAFS. At the Indian Ocean Station, the Philco personnel who operate the tracking site under contract to SSD, inserted the test tapes simultaneously into both TD heads (tape readers). The output of the TD heads went to the respective error control devices, whose outputs were sent to the RCA-operated communications site, also on Mahe, for transmission to Ascension Island, the relay point. Since the TD-12 output consists of two data streams (information and parity), two channels (#13 and #14) of the AN/FGC-60 were required to transmit the data. Two FGC-60 channels (#9 and #10) were also used to transmit the one EDAC output stream thus providing it with in-band frequency diversity protection.

These signals were received at Ascension and demodulated. The TD-12 channels were synchronously regenerated, and both systems were retransmitted to Cape Kennedy.

At Cape Kennedy, the audio signals were received on radio receivers using diversity-spaced antennas. Therefore, due to the in-band diversity used with EDAC, that system was operating under quad-diversity conditions while the TD-12 had dual-diversity. At both terminals, line isolation relays were used to convert the neutral inputs and outputs, required by the TD-12, to polar signals for use with the FGC-60.

Because the EDAC transmitting terminal must be continuously updated as to the quality of the received message blocks, another identical teletype circuit was necessary from the receiver to the transmitting terminal. The ARQ information was time multiplexed into each block along with any regular traffic being handled at that time. Therefore, a full duplex teletype circuit was required.

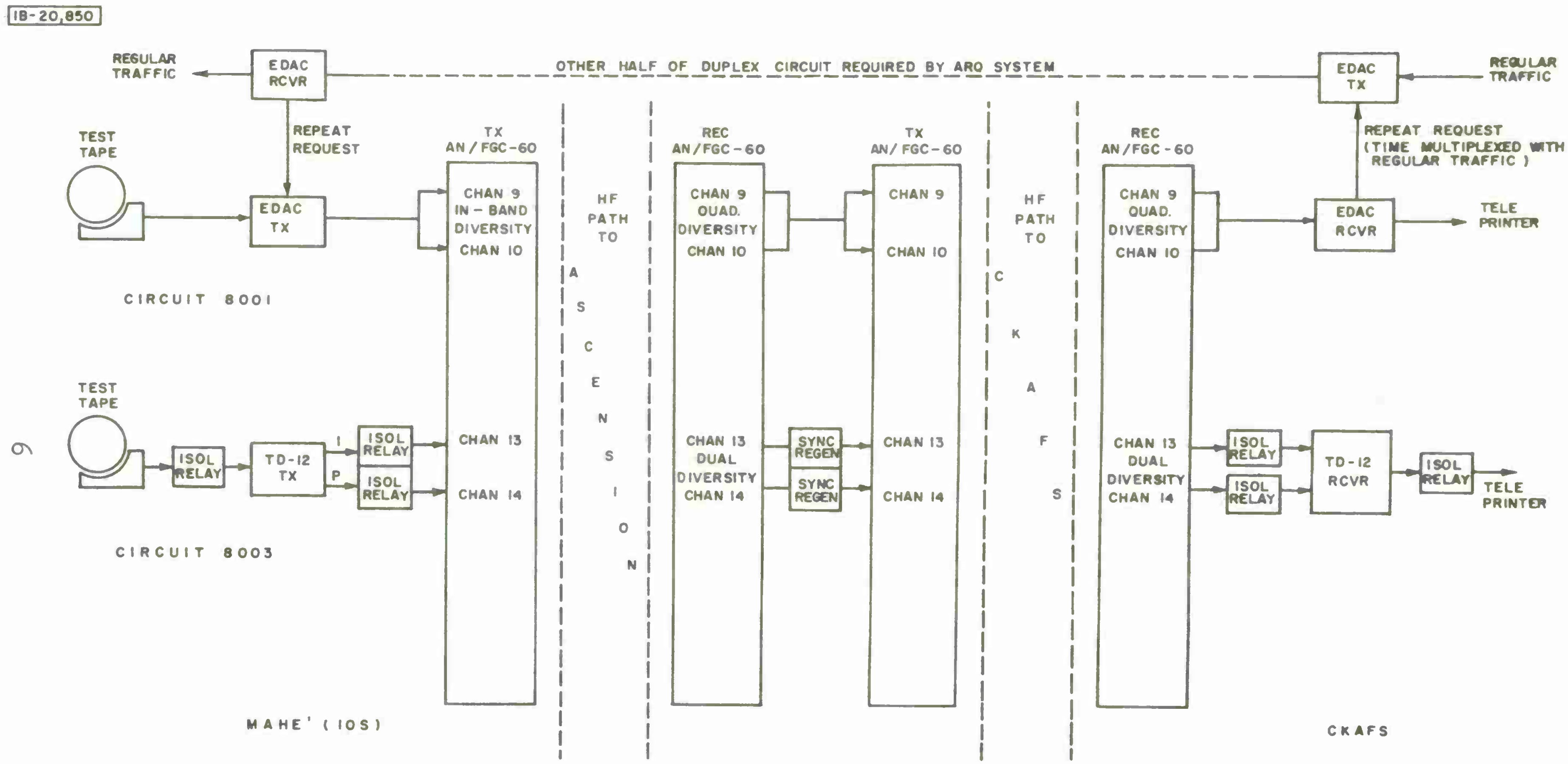

Figure 1 EQUIPMENT CONFIGURATION

SECTION VI

DATA REDUCTION

In order to simplify and standardize the data reduction process, a special test message was transmitted. This message consisted of 10 blocks of teletype characters. Each block contained 10 lines of 790 teletype characters, seven of which were non-printing characters. The following character format was used for each line: UPPER CASE, NUMBER OF THE LINE, LOWER CASE, SPACE, 70 ALTERNATE LETTER R AND LETTER Y CHARACTERS, THE LETTER E, TWO CARRIAGE RETURNS AND TWO LINE FEEDS (see Figure 2). Sufficient line feeds were provided to separate the individual blocks.

At the receive terminal, the R, Y, 4 and 6 type bars were removed from the typing block of the teletype page printer. (The 4 and 6 type bars were removed of necessity since they are upper case portions of the R and Y bars respectively.) Therefore, the only printing characters which should appear on the page copy are the line numbers (minus the 4 and 6 characters) and the letter E at the end of each line except for undetected or uncorrected errors. The occurrence of nonprinting character errors are identified relative to the printed characters which occurred. A sample of received page print with typical errors is shown in Fig. 3.

There are two possible ways in which to compare the operational performance of the two systems. The first method which involves just looking at the character error rate performance, neglects the additional time required by the ARQ system to retransmit and recheck the blocks in which errors were previously detected. The second method includes the time differential and compares the performances of the two systems from a "throughput" basis, i.e., it takes into account which system sent the most amount of <u>correct</u> information per unit time.

A total of 8800 teletype characters were received from the 14 minutes and 40 seconds duration of each transmitted paper tape test run, i.e.,

$$100 \text{ words}/_{\text{min}} \times 6 \text{ char}/_{\text{word}} = 600 \text{ char}/_{\text{min}}$$

and

$$600 \text{ char}/_{\text{min}} \times 14.66 \text{ min} = 8800 \text{ char.}$$

Therefore, the sample size of each test was 8800 characters. The average character error rate of each system was determined

```
1  RYRYRYRY . . . . . . . . . . . . . . . . . . . . .  RYRYE
2  RYRYRY   . . . . . . . . . . . . . . . . . . . . .  RYRYE
3  RYRY . . . . . . . . . . . . . . . . . . . . . . .  RYRYE
4  RYRY . . . . . . . . . . . . . . . . . . . . . . .    RYE
5  RYRY . . . . . . . . . . . . . . . . . . . . . . .    RYE
6  RYRY . . . . . . . . . . . . . . . . . . . . . . .    RYE
7  RY . . . . . . . . . . . . . . . . . . . . . . . .    RYE
8  RY . . . . . . . . . . . . . . . . . . . . . . . .    RYE
9  RY . . . . . . . . . . . . . . . . . . . . . . . .    RYE
0  RY . . . . . . . . . . . . . . . . . . . . . . . .    RYE
   |<--------------- 70 CHARACTERS --------------->|

1  RYRY                                                  RYE
2       etc.
```

Figure 2. Transmitted Teletype Format

1	Q ← 1 error		E
2			E
3			E
			E
5			1 error → 3
	SSDD ← 4 errors		
7			E
8			E
9			E
0			E
		1 error → E	
1			E
2	ETC.		

Figure 3. Sample of Received Teletype Format

by totalizing the character errors and dividing them by the total characters received.

The throughput of each system was calculated from the following formula:

$$\text{Throughput} = \frac{\text{Total Characters - Character Errors}}{\text{Total Time}}$$

Based upon the ARQ system data, computations were also made to provide an approximation of the level of performance of the unprotected (no error control) teletype circuit operating at the same time. Assuming that each character error generates a request for retransmission, the amount of delay measured on the ARQ-protected circuit may be translated into errors. Hence, the total of the undetected character errors and the errors implied by the delay provides the total number of character errors that occurred. The character error rate of the approximated unprotected channel is then the ratio of the total character errors and number of total characters that were sent during the test time.

Since each request for retransmission utilizes 2 encoded blocks (the erroneous block and the block being transmitted), 8 characters are lost. Therefore, the unprotected character error rate (CER) may be approximated by:

$$\text{CER} = \frac{\text{DELAY} \times \frac{\text{1 ARQ}}{\text{8 CHAR}} \times \frac{\text{1 CHAR ERROR}}{\text{ARQ}} \times 10\ \frac{\text{CHAR}}{\text{SEC}} + \text{UNDETECTED ERRORS}}{\text{TOTAL TIME} \times 10\ \frac{\text{CHAR}}{\text{SEC}}}$$

which reduces to

$$\text{CER} = \frac{1.25 \times \text{DELAY} + \text{UNDETECTED ERRORS}}{\text{TOTAL TIME} \times 10}$$

with the Total Time and the Delay in secs.

SECTION VII

RESULTS AND CONCLUSIONS

The curves of Fig. 4 indicate, on a cumulative basis, the percent of test runs during which each system operated equal to or less than a specific character error rate without regard to delay. Also included is the calculated curve showing the approximated operation of a system operating without error control. During 27 of the 37 total 14.66 min. test samples, the EDAC equipment operated error-free, while the TD-12 equipment operated error-free only once.

The median character error rate for the TD-12 was 2.0×10^{-3} while that of the calculated unprotected circuit was 7.2×10^{-3}. It should be noted that this computed curve is a best case situation; i.e., if more than one character error occurred in the 8 character ARQ block involved, the actual performance would be worse than that shown in Fig. 4.

The cumulative character error rate curve for the EDAC equipment is really a measure of the error detection properties of the code as indicated by the failure of the code to detect errors. Consequently it can be seen that in 27% of the test runs the EDAC failed to detect at least one character error in the 14.66 min. run.

In order to determine the time delay impact of the ARQ system, the throughput for both the Codex TD-12 and Western Union EDAC equipment has been determined and the cumulative throughput plotted in Fig. 5. If there were no errors and no interruptions in transmission the throughput would be 10 five bit teletype characters per second. It will be noted that the output of the TD-12 equipment never decreased below 9.7 correct characters per second. With the EDAC equipment, however, each interruption to retransmit a block with errors reduces the throughput (e.g., 27% of the time the throughput was less than 9 characters per second). At no time does the throughput of the EDAC equal that of the TD-12.

An overall summary of the test results is shown in Table I. In general, it appears that the TD-12 equipment provides an order of magnitude improvement in character error rate over an unprotected system and permits the employment of on-line security equipment for secure communications. The EDAC equipment, on the other hand, provides to the subscriber an order of magnitude of character error rate improvement over the TD-12 equipment, but at somewhat greater than 10% sacrifice in throughput. In addition, the EDAC traffic cannot be secured with on-line security equipment and a full duplex link must be maintained.

18-20,852

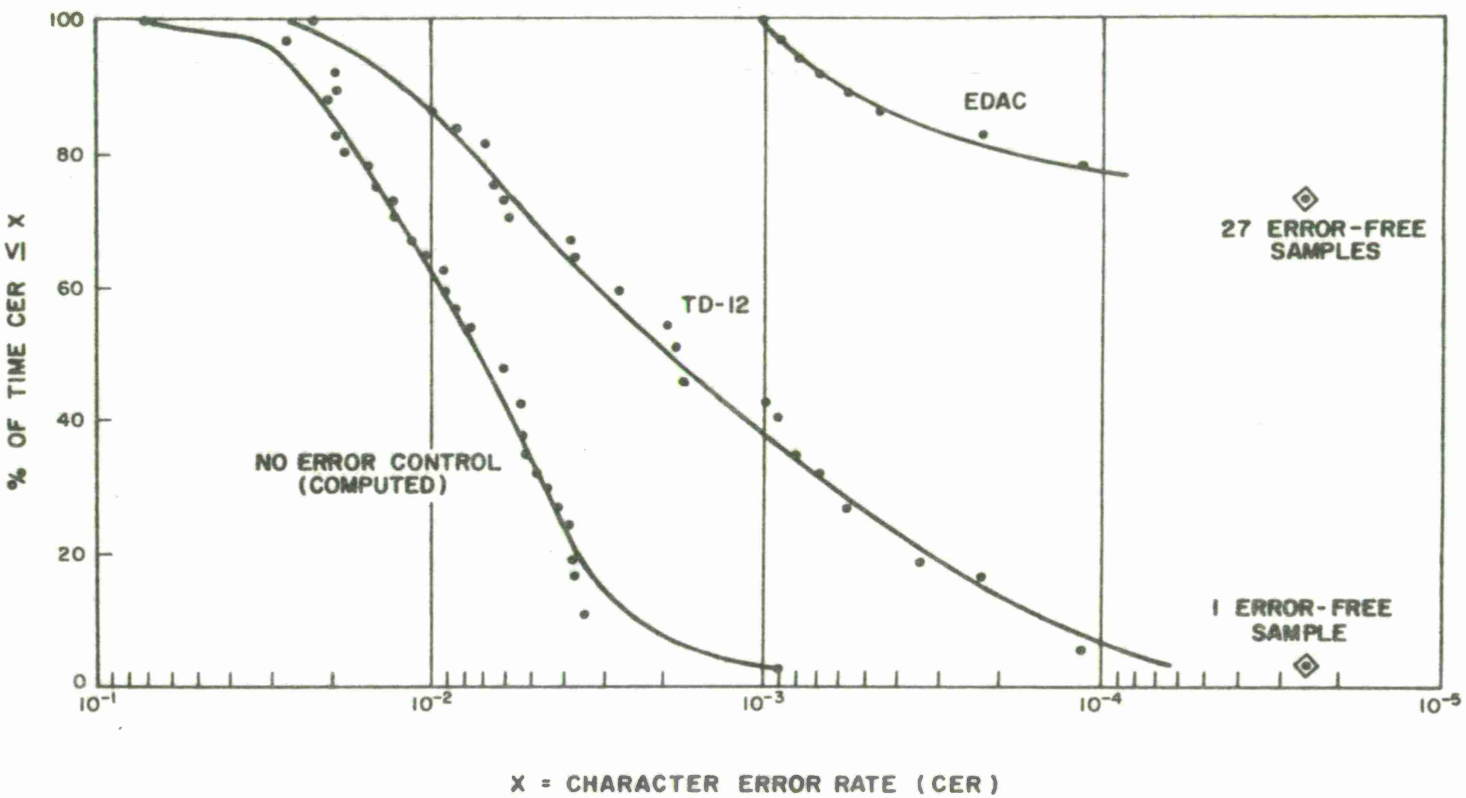

Figure 4 CUMULATIVE PERFORMANCE VS. CER

1A-20,851

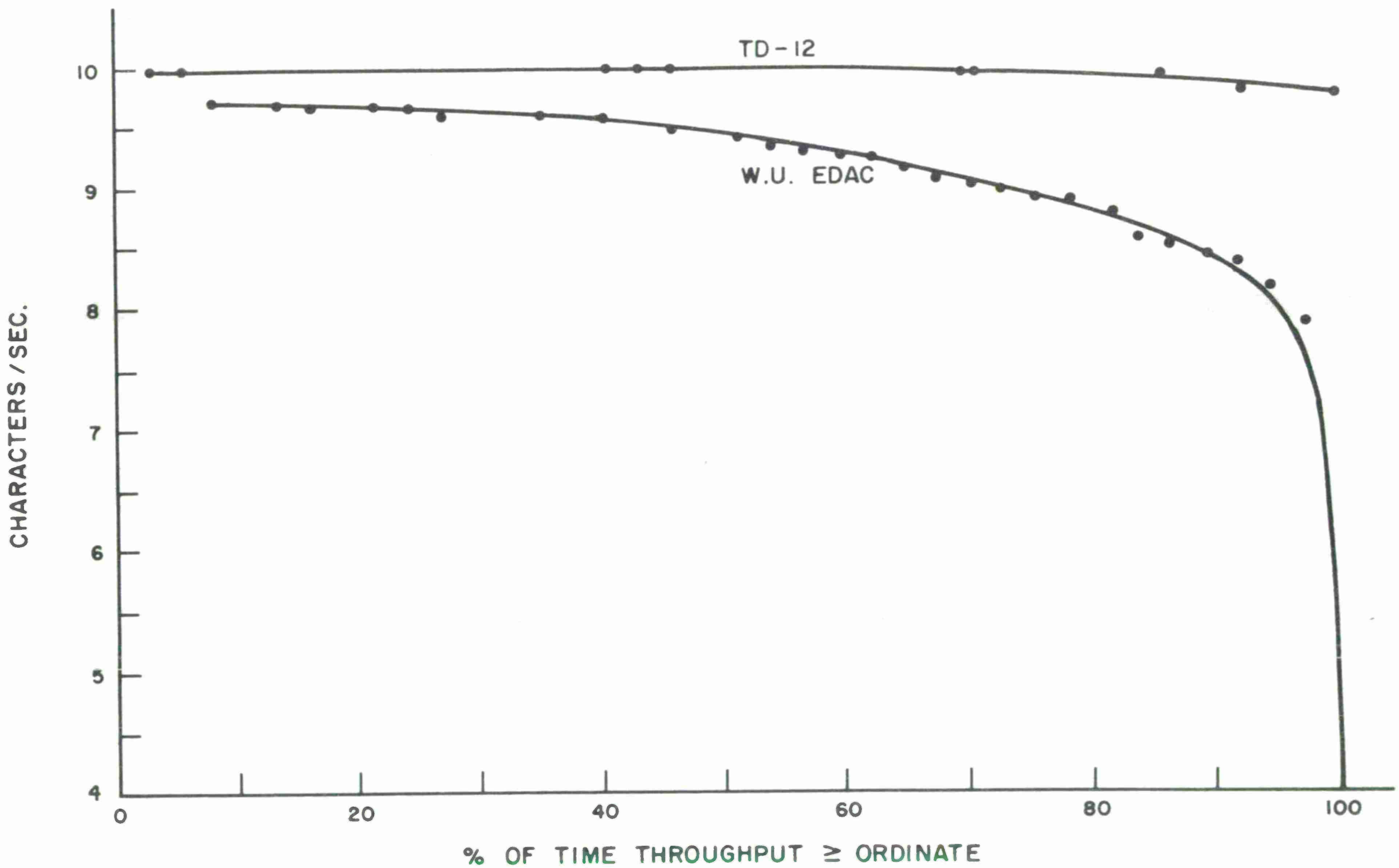

Figure 5 CUMULATIVE PERFORMANCE OF CHARACTER TRANSMISSION RATE

TABLE I

TEST RESULTS

	FEC Circuit 8003 Codex TD-12	ARQ Circuit 8001 Western Union EDAC
Total Number of Characters Transmitted	325, 600	325, 600
Total Number of Uncorrected Character Errors	1653	45
Overall Average Character Error Rate	5.08×10^{-3}	1.38×10^{-4}
Total Time to Transmit the Data	9 hrs. 2.7 min.	10 hrs. 8.2 min.
Ratio of Actual Time to Real Time	1.0	1.12

The determination as to which is the system to use, therefore, must be dicatated by the operational concept of the communications system into which the error control system is to be incorporated. For example, if the objective of the communications system is to minimize the number of errors received, regardless of the time required to transmit the information, and a full duplex circuit is available, then the ARQ technique may be most applicable. However, if the information to be transferred must be secured and obtained in real time, or if only simplex transmission is desired, then the FEC technique appears to be more suitable.

Neither system tested can completely cope with the anomalies inherent in the HF propagation path and therefore neither can guarantee that the subscriber will receive traffic completely free of errors.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) The MITRE Corporation Bedford, Massachusetts	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Performance Evaluation of Teletype Error Control Equipment on an ETR Circuit

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

N/A

5. AUTHOR(S) (First name, middle initial, last name)

NELSON, Frederick N. Jr.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1967	20	0

8a. CONTRACT OR GRANT NO. AF 19(628)-5165	9a. ORIGINATOR'S REPORT NUMBER(S) ESD-TR-67-121
b. PROJECT NO. 705B	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) MTR-366
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Deputy for Surveillance and Control Systems, Aerospace Instrumentation Program Office, Electronic Systems Div., L. G. Hanscom Fld., Bedford, Mass.

13. ABSTRACT

This report describes a series of teletype transmission tests made over an HF radio link between Mahe Island and Cape Kennedy, Florida. Two methods of error control protection were employed and their relative performances evaluated.

DD FORM 1 NOV 65 1473

Unclassified

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Teletype Transmission Tests						
HF Radio Link						
Error Control Protection						
Error Control Equipment						
ETR Circuits						